EVALUATION OF GRADE AND STRAIGHTEDGE TOLERANCES IN FEDERAL AVIATION ADMINISTRATION PAVEMENT CONSTRUCTION SPECIFICATIONS

By:
Jeffrey Rapol
Civil Engineer, Airport Engineering Division
Federal Aviation Administration, AAS-100
800 Independence Ave., SW
Washington, DC 20591, U.S.A.
Tele: (202) 267-7474; Fax: (202) 267-5383; email: jeffrey.rapol@faa.gov

PRESENTED FOR THE 2002 FEDERAL AVIATION ADMINISTRATION TECHNOLOGY AIRPORT TRANSFER CONFERENCE

05/02

Evaluation of Grade and Straightedge Tolerances in Federal Aviation Administration Pavement Construction Specifications

Jeffrey Rapol
Civil Engineer, Airport Engineering Division
Federal Aviation Administration, AAS-100
800 Independence Ave., SW
Washington, DC 20591, U.S.A.
Tele: (202) 267-7474; Fax: (202) 267-5383; email: jeffrey.rapol@faa.gov

ABSTRACT

Federal Aviation Administration (FAA) specifications for runway, taxiway, and apron pavements contain acceptance criteria based on grade and straightedge tolerances (1). Recent specifications have focused on measured profile indices as a primary acceptance measure for pavement smoothness during construction. The FAA recognizes this and funds research into runway pavement ride quality with the goal of quantifying smoothness acceptance criteria. The research is being conducted at the FAA's William J. Hughes Technical Center, Atlantic City, New Jersey. It should help define what makes a pavement too rough for routine aircraft operations. Pending results of this research, interim guidance using California profilograph tests has been added to FAA airfield pavement specifications on a project-by-project basis (2).

Understanding the relationship between proposed pavement smoothness criteria and historically successful grade and straightedge construction tolerances is necessary before incorporating smoothness acceptance criteria into the standard specifications. A method to quantify this relationship that show promise is a software product of the on-going research. The software, called PROVIEW, can analyze runway profile data using static profile indices and dynamic force indices. PROVIEW was used in this study to analyze synthesized runway profiles that meet certain grade and straightedge tolerances and to compare field collected profile data to simulated runway profiles.

The paper summarizes the method used to simulate and analyze runway profiles. The simulated profiles were modeled for selected static and dynamic indices available in the software, with special emphasis on the California Profilograph Index (PI), the International Roughness Index (IRI), the Boeing Bump Index, and the dynamic forces on the nose gear. The models were used to evaluate field-measured profiles and the current smoothness criteria used in some FAA projects.

The paper will present:

- Technique used to generate random grade and straightedge deviations from a design profile;
- Grade and Straightedge tolerance models for static and dynamic indices;
- Comparison of results to field-measured profiles;
- Analysis of FAA acceptance criteria.

The results of this study may form the basis to reconcile current differences in acceptance criteria that have been identified in FAA pavement specifications and to develop smoothness acceptance criteria compatible with grade and straightedge requirements.

INTRODUCTION

In February 2001, a Federal Aviation Administration (FAA) regional pavement engineer indicated that a formal request to modify the straightedge and grade acceptance tolerance was being contemplated. The request would relax acceptance criteria for pavements constructed at smaller airports. Current FAA guidance covers all pavements regardless of location. FAA grade and straightedge acceptance criteria are pass/fail at 85 percent within limits (PWL). For grade acceptance, 85% of measurements taken at 50-foot intervals must be less than one-half inch (1 part in 1200) from design grade. For straightedge acceptance, 85% of measurements taken with a 12-foot straightedge must be less than one-quarter inch (1 part in 576). One impetuous for the request was the lack of detailed guidance in the specification for pavements constructed out-of-tolerance.

FAA pavement construction standards are rarely changed and lesser standards must provide an equivalent level of safety and performance. It was decided to pursue a technical evaluation of current acceptance criteria using research products under development at the FAA's Technical Center. If the evaluation proved feasible and the results warranted a change, the rigorous process used to institute a change to FAA construction standards would begin.

FAA specifications do not contain a reporting requirement for grade and straightedge measurements. As long as the number of out-of-tolerance readings is less than 15%, the pavement may be accepted. The lack of a reporting requirement means the FAA does not have data to analyze. A method to fabricate reasonable data was needed along with a method to analyze the data against roughness indices. This paper presents the method used to fabricate profile data at various quality levels and the analysis of that data against acceptance criteria.

STUDY APPROACH

Two requirements were necessary to enable the study. The first requirement was a method to evaluate profile data. The method used was software developed as part of on-going research into airfield pavement smoothness (3). The software has been named PROVIEW by the developers, after PROfile VIEWer. This software is available upon request from the William J. Hughes Technical Center. PROVIEW provides accurate profile analyses in accordance with some widely recognized profile indices. The profile indices used in this study are described below.

1. Straightedge Index calculates the average deviation along a straightedge of user-defined length. The method used does not assume either end of the straightedge is in contact with the pavement. It incorporates a concept called the "upper convex hull". The index is reported as an average in inches. A 12-foot user-defined straightedge length was used for this study, the same straightedge length requirement in FAA flexible pavement construction specification.

2. The International Roughness Index is detailed in other publication and in ASTM E 1170 (4)(5). This index is reported in meters per kilometer. A check on the accuracy of the algorithm used to calculate this index was accomplished with the cooperation of APR Consultants and the Ames Engineering Company.

3. The Boeing Bump Index is detailed in other publications (6). It is reported as a ratio of Boeing bump divided by an acceptable Boeing bump. Values less than 1 indicate a bump will not cause immediate damage to an aircraft. Values in excess of 1 indicate damage to the aircraft is possible. Values in excess of one are considered unacceptable. Values of about 0.25 seem reasonable for new construction. A check on the accuracy of the algorithm used to calculate this index was accomplished with the cooperation of APR Consultants (www.aprconsultants.com).

4. The California Profilograph Index is detailed in other publication and in ASTM E 1274 (7). The index is reported in inches per mile and incorporates a 0.2-inch blanking band. A check on the accuracy of the algorithm used to calculate this index was accomplished with the cooperation of the Ames Engineering Company (www.amesengineering.com).

The details of the algorithms and the method used to calculate the various indices will be detailed in reports that document the research and are outside the expertise of the author and beyond the scope of this paper.

The second requirement to enable the study was a method to fabricate profile data that simulate the grade and straightedge tolerance limits contained in FAA specifications. This was accomplished with a commercially available risk analysis software package called Crystal Ball© (8), a set of Excel© (9) add-in functions that allows the user to generate simulations based on a defined probability distribution function using two random sampling techniques. The first sampling technique is the Monte Carlo simulation, which works by randomly selecting any valid value from a probability distribution over and over to simulate a model. The second is the Latin Hypercube simulation, which works by segmenting a probability distribution into a number of non-overlapping intervals, each having equal probability. Then, from each interval, a value is selected at random according to the probability distribution within the interval. Latin Hypercube sampling is generally more precise for producing random samples than conventional Monte Carlo sampling because the full range of the specified distribution is sampled in a more even and consistent manner that requires a smaller number of trials to achieve the same accuracy (8). Since sampling would be at 50-foot and 12-foot intervals over the length of a runway pavement, the relatively small number of samples, 200 for grade and 800 for straightedge, indicates the Latin Hypercube to be the best random sampling method for this study.

STEPS TO GENERATE PROFILE DATA

A series of idealized runway profile with random elevation deviations at 50-foot (grade) intervals and random elevation deviations at 12-foot (straightedge) intervals were generated. The steps used to accomplish this were as follows:

1. A 10,000-foot runway profile with reasonable elevation changes was established. Table 1 shows the vertical alignment used for all simulated runway profiles.

Table 1. Runway Vertical Alignment.

Station (ft.)	Elevation (in.)
0	100
1,250	136
5,000	40
8,750	136
10,000	100

2. A cubic spline curve was fit to the profile with an Excel spreadsheet function (10) and elevations at 50-foot intervals were determined.

3. Random grade deviations were generated at 50-foot intervals based on 15% of the deviations exceeding a set tolerance (e.g. 15% of the deviations exceeding +/- 0.50 inches).

4. The random deviations were merged with the 50-foot interval elevations and a cubic spline curve was re-fit through the modified 50-foot elevations.

5. The quarter-point elevations (12.5-foot intervals) were determined and a set of random straightedge deviations were generated at 12-foot intervals based on 15% of the deviations exceeding a set tolerance (e.g. 15% of the deviations exceeding + 0.25 inches). The deviations assume the ends of the straightedge are in contact with the pavement.

6. The straightedge deviations were merged with the profile at randomly chosen intervals along each 12.5-foot interval, with a separate check to ensure that the straightedge deviations did not cause the grade deviations to exceed tolerances.

7. A cubic spline curve was re-fit through the modified profile and processed using PROVIEW. The steps were repeated using the Table 1 profile and the same set of random numbers to generate profiles with a range of grade and straightedge deviations.
Figures 1A though 1C graphically present the resulting profile.

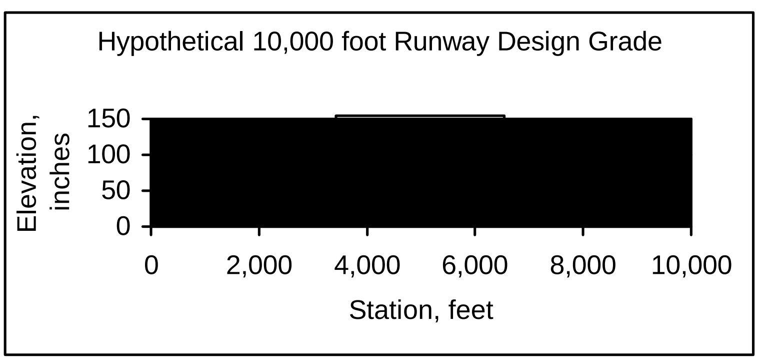

Figure 1A. Hypothetical 10,000 foot Runway at Design Grade.

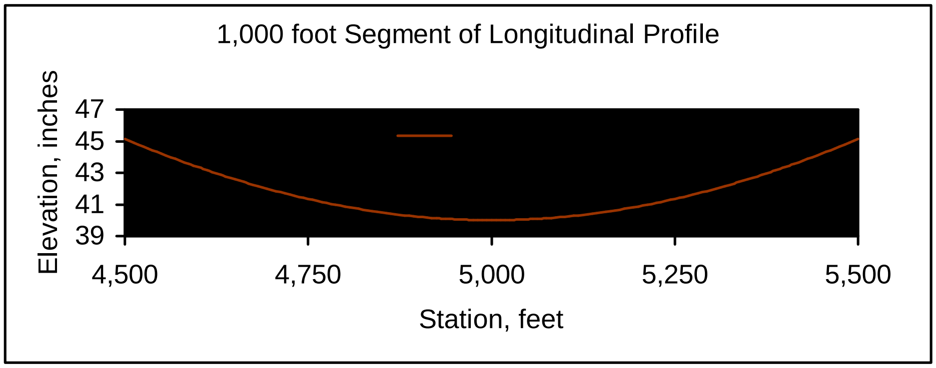

Figure 1B. Segment from Station 4,500 to Station 5,000 at Design Grade.

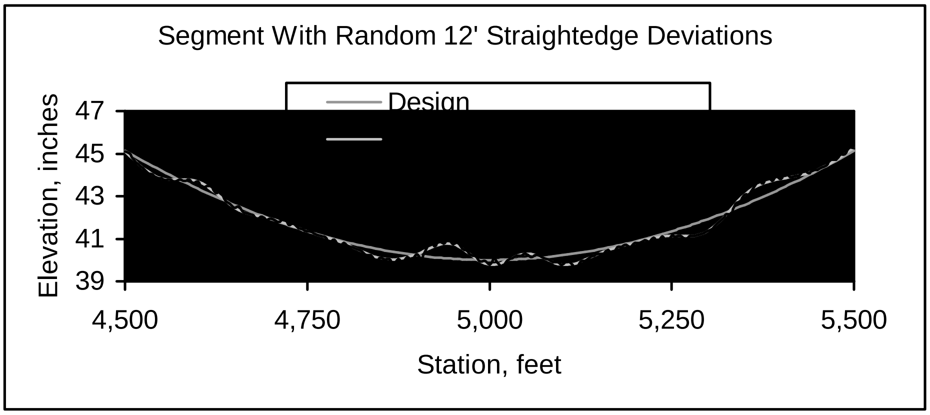

Figure 1C. Segment of Profile with Random Grade and Straightedge Deviations

CORRELATION OF INDICES TO GRADE AND STRAIGHTEDGE TOLERANCES

The method described above was used to generate a series of profiles with the grade and straightedge tolerances listed in Table 2. In all, 100 combinations were analyzed. Figure 2 is a screen print of the PROVIEW output screen.

TABLE 2. Ranges of Grade and Straightedge Tolerances Analyzed

Straightedge Tolerance (in.)	Percent Out-of Tolerance	Grade Tolerance (in)	Percent Out-of Tolerance
0.05	15%	0.125	15%
0.10	15%	0.250	15%
0.15	15%	0.375	15%
0.20	15%	0.500	15%
0.25	15%	0.625	15%
0.35	15%	0.750	15%
0.45	15%	0.875	15%
0.55	15%	1.000	15%
0.65	15%	1.125	15%
0.75	15%	1.250	15%

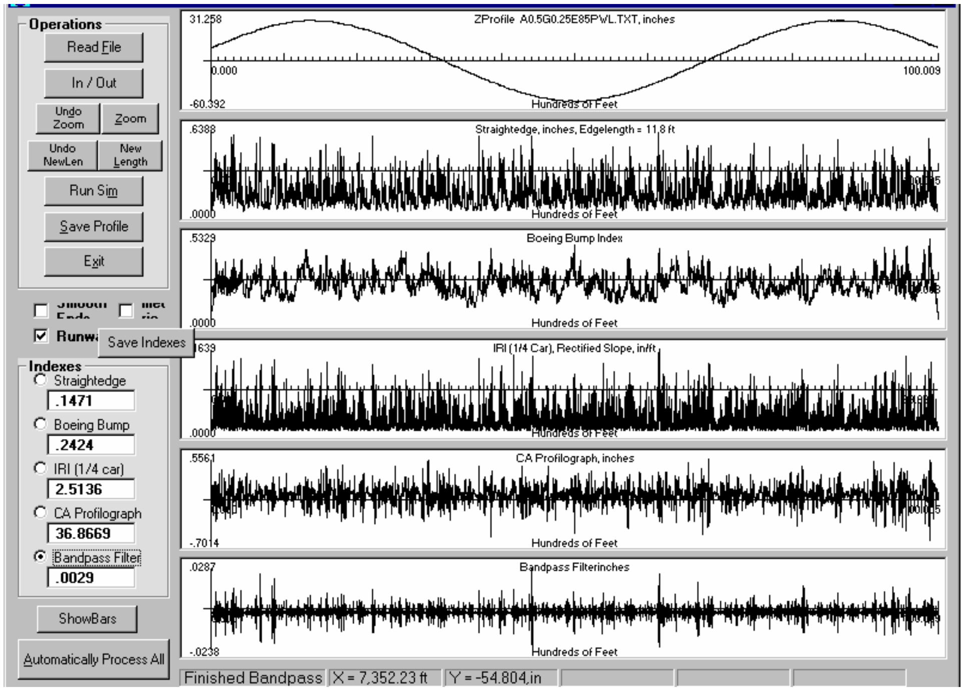

Figure 2. Screen Print of PROVIEW Output Screen

The series of figures that follow present correlations for PROVIEW generated Indices against the simulated smoothness acceptance criteria at 15% out-of-tolerance, which is equivalent to a quality level of 85 PWL.

Straightedge Index. The comparison of the straightedge index to the simulated straightedge tolerance is useful because the method used to generate the straightedge deviations for the profile differs from the method used to calculate the straightedge index. Figure 3 shows good agreement for the correlation. It was confirmed that, on average, a 12-foot straightedge length is not sensitive to 50-foot grade tolerances as shown by the tight grouping of grade tolerance values at each straightedge tolerance increment.

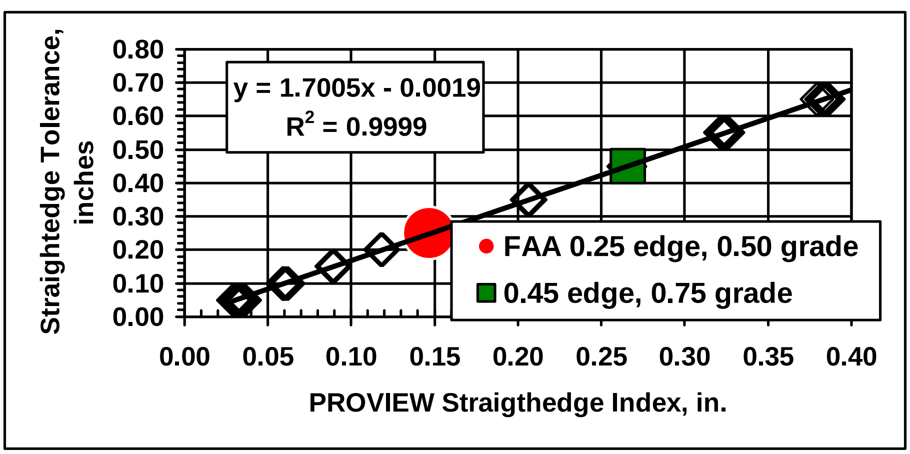

Figure 3. Straightedge Index vs. 85 PWL Straightedge Tolerance

International Roughness Index (IRI). The comparison of the IRI to the simulated profiles is shown in Figure 4. The IRI exhibits a modest amount of sensitivity to grade tolerance when the pavement is smooth, less than 1 m/km, by IRI standards. However, as the IRI increases the grouping of grade tolerance values as the straightedge tolerance value increases becomes tighter. This confirms that the IRI is not sensitive to the 50-foot grade tolerance.

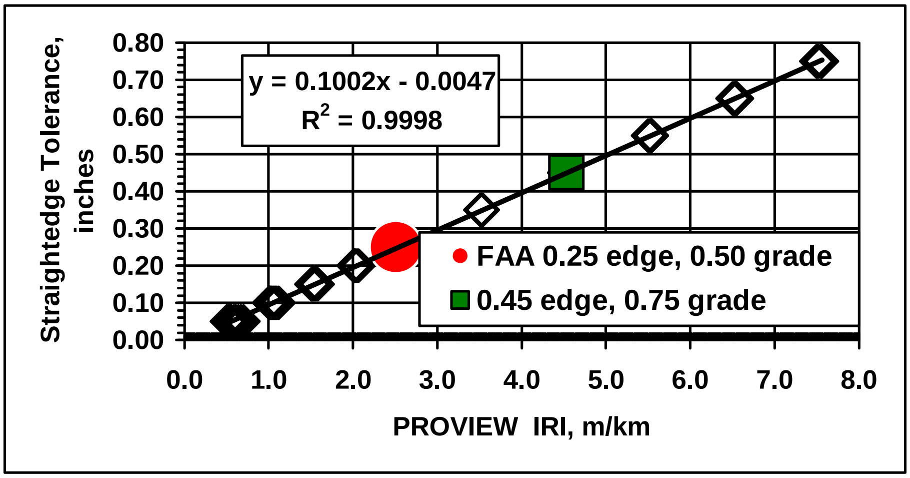

Figure 4. IRI vs. 85 PWL Straightedge Tolerance

California Profilograph Index (PI). The comparison of the PI to the simulated profiles is shown in Figure 5. The PI shows substantial sensitivity to the 50-foot grade tolerance at straightedge tolerances at or below the FAA standard. There is a decreasing sensitivity as the grade tolerance increase beyond the 0.25-inch standard. However, the level of sensitivity may prove too small to use as a basis for stand-alone smoothness acceptance criteria development.

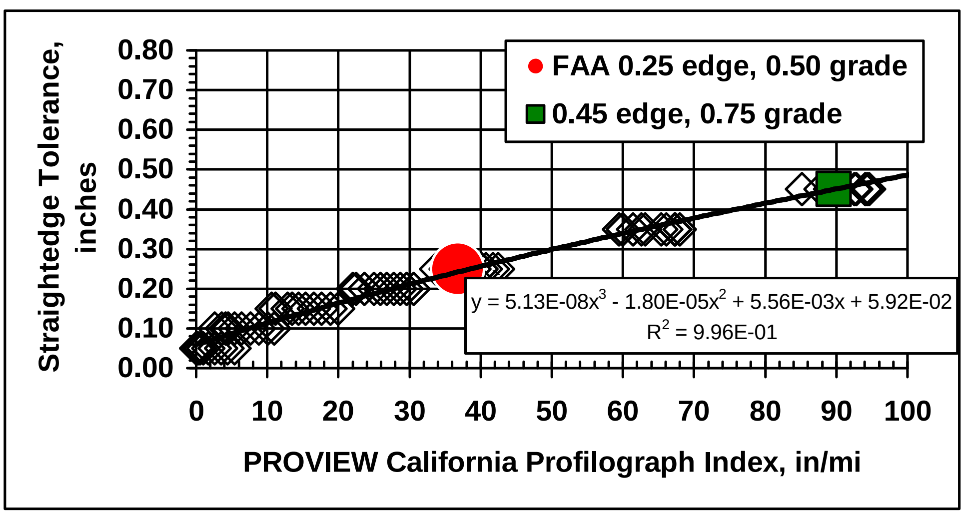

Figure 5. California Profilograph Index vs. 85 PWL Straightedge Tolerance

Boeing Bump Index. The method used to calculate the Boeing Bump, (a series of ever-increasing straightedge measurements) is very conducive to analysis of the two smoothness parameters used for acceptance. Figure 6 shows a very substantial sensitivity to both 12-foot straightedge criteria and 50-foot grade tolerance criteria. The level of sensitivity should be well suited to use as a stand-alone method to develop smoothness acceptance criteria. This sensitivity can be used in conjunction with the insensitivity of the other profile indices to make judgments regarding the estimated grade and straightedge deviations from measured runway profiles, as explained later.

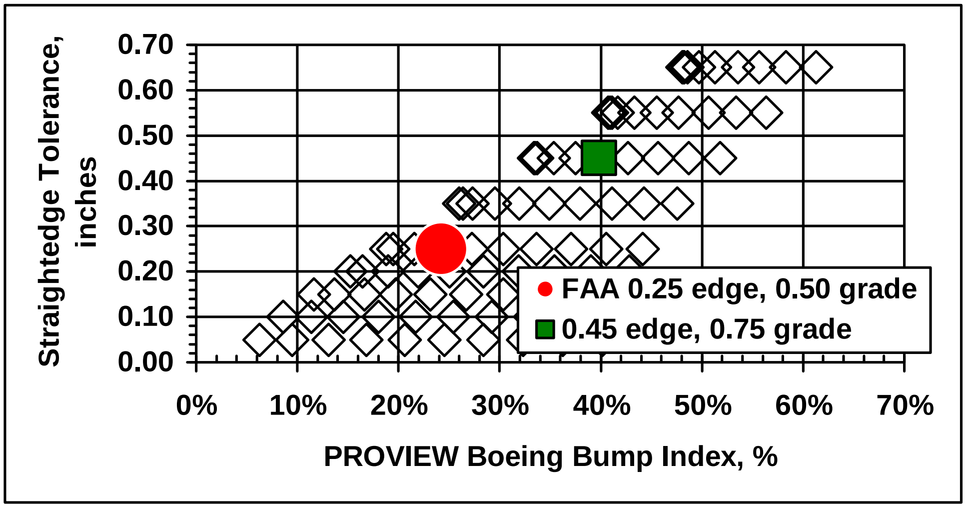

Figure 6. Boeing Bump Index vs. 85 PWL Grade Tolerance

CORRELATION TO DYNAMIC FORCES

The study included an evaluation of aircraft moving over the simulated profiles. The dynamic response of the nose gear and the landing gear for two aircraft were included in this study. The aircraft were the Boeing 727 and the DC-9 aircraft. Moving simulations speeds of 20-knots and 100-knots were used. The grade and straightedge tolerances from Table 2 were used in the analysis. Plots of the tolerances versus the maximum dynamic load responses at the nose gear and main gear of the aircraft are shown in the following figures.

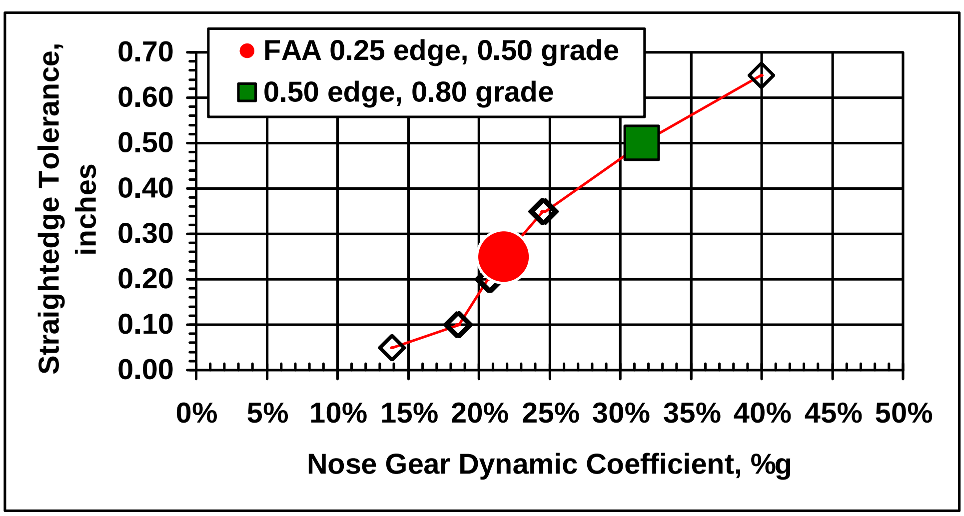

Figure 7A. DC-9 at 20 knots, Nose Gear vs. 85 PWL Straightedge Tolerance

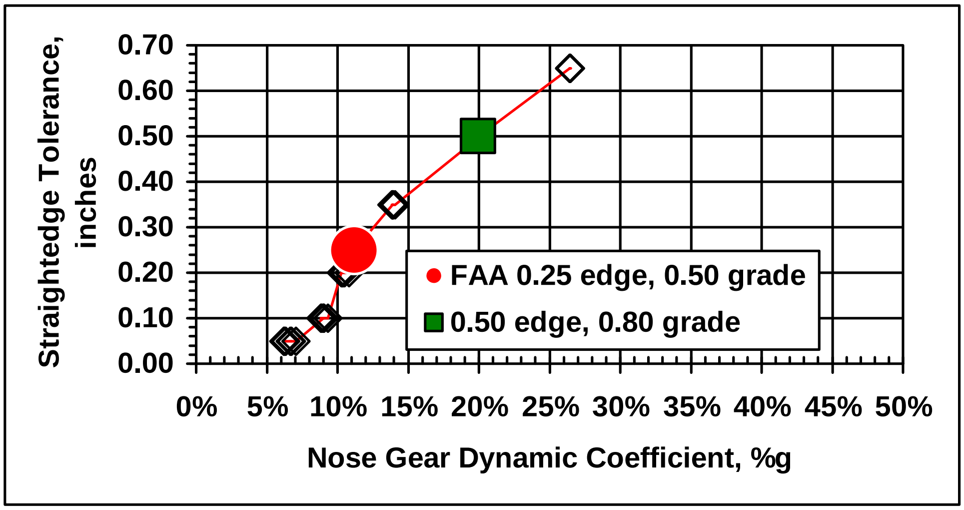

Figure 7B. Boeing-727 at 20 knots, Nose Gear vs. 85 PWL Straightedge Tolerance

In comparing Figures 7A and 7B, neither aircraft is overly sensitive to grade tolerances at 20-knots as shown by the tight grouping of grade tolerance values at each straightedge tolerance increment. The smaller aircraft exhibits larger dynamic forces as a result of the grade and straightedge deviations. Indications are that grade and straightedge tolerances are not as critical to aircraft at lower speeds which indicates that taxiway and apron pavements would not have to be held to as high a standard as runway pavements. However, the controlling features of these pavements may not be aircraft response. Drainage, snow removal, and the response of smaller service vehicles may be the control for these pavements.

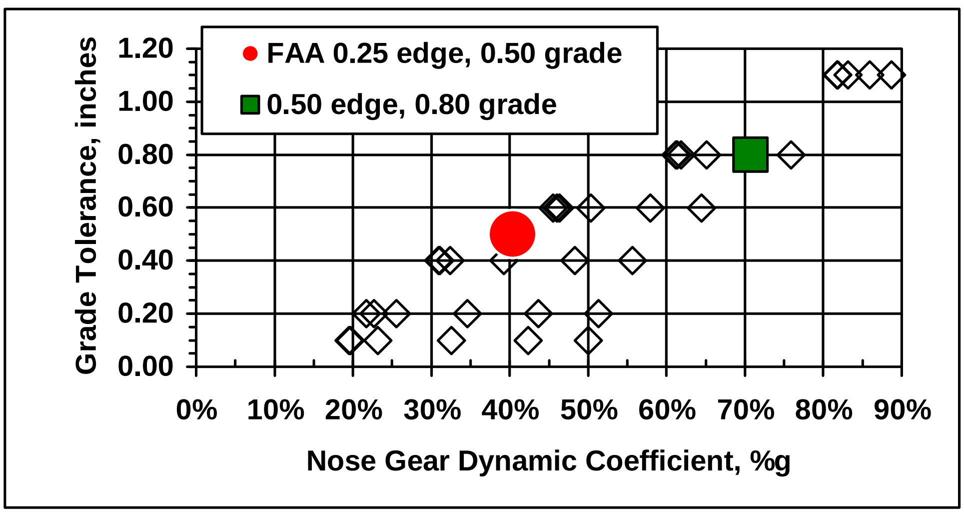

Figure 8A. DC-9 at 100 knots, Nose Gear vs. 85 PWL Straightedge Tolerance

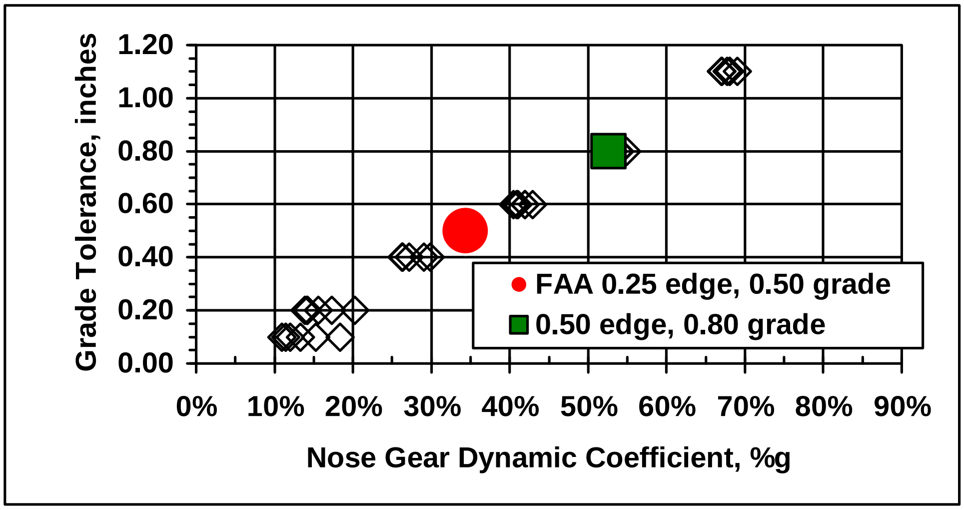

Figure 8B. Boeing-727 at 100 knots, Nose Gear vs. 85 PWL Straightedge Tolerance

In comparing Figures 8A and 8B, it is apparent that different aircraft respond differently at higher speeds. Each aircraft shows a between 30-40% dynamic load due to grade and straightedge deviations if a pavement just meets the current FAA criteria. The smaller aircraft is more sensitive to straightedge deviation at these speeds than the larger aircraft as shown by the loose grouping of straightedge tolerance values at each grade tolerance increment. The data indicate that, if anything, the FAA should consider further restricting the current construction criteria for runway pavements. Relaxing the grade and straightedge criteria for runways that serve smaller aircraft may lead to roughness complaints by pilots.

COMPARISON TO MEASURED PROFILES

The on-going research included numerous profile measurements on several runways at selected airports. A small number of comparisons between field-measured and model estimated indices are shown in Table 3.

TABLE 3. Five Runways Compared to Simulation Correlations

PROVIEW Results from Measured Runway Profiles				
Runway ID	**12-foot Straightedge Index, in**	**Boeing Bump Index**	**IRI, m/km**	**California Profilograph, in/mi**
E18Ll1	0.0964	0.1626	1.5123	7.9184
Md3120l1	0.1217	0.2308	2.0561	23.3422
Md3120r1	0.1244	0.2260	2.0780	27.0553
MD1320L1B	0.1247	0.2195	2.0806	27.5494
Cho121r1	0.0575	0.1369	1.0807	5.0816
85 PWL Tolerances Estimated from Correlations				
Runway ID	**Estimated Straightedge Tolerance**	**Estimated Grade Tolerance**		
E18Ll1	0.1577	0.3750		
Md3120l1	0.2379	0.5250		
Md3120r1	0.2504	0.4875		
MD1320L1B	0.2520	0.4500		
Cho121r1	0.1103	0.3375		
PROVIEW Results Using Estimated 85 PWL Tolerances				
Runway ID	**12-foot Straightedge Index, in**	**Boeing Bump Index**	**IRI, m/km**	**California Profilograph, in/mi**
E18Ll1	0.0927	0.1697	1.5855	14.48
Md3120l1	0.1398	0.2429	2.3929	34.58
Md3120r1	0.1473	0.240	2.5172	36.84
MD1320L1B	0.1488	0.2316	2.5377	36.16
Cho121r1	0.065	0.1396	1.113	5.51

The comparisons were accomplished as follows:

Run Proview on a measured runway profile (e.g., E18Ll1.pro). Find the estimated straightedge tolerances using the regression equations from Figures 2, 3, and 4. Average the three estimated straightedge tolerances, enter Figure 5 at the PROVIEW Boeing Bump Index value. Project a line vertically until it intersects the estinated straightedge tolerance. Project a line horizontally from the intersection of Boeing Bump and estimated straightedge tolerance to the Grade tolerance axis. Read the estimated grade tolerance. Generate an idealized runway profile, using the estimated straightedge and grade tolerances tolerances. Compare the estimated indexes from the idealized simulation to measured indexes.

The results of the comparison indicate that simulating profiles based on the correlations result in indices that compare well, on average, with the Straightedge index, the Boeing Bump index, and the IRI. The comparison to the PI does not compare well with the PI from the measured profile PI at lower PI values. As mentioned earlier, the PI is sensitive to both smoothness acceptance criteria at lower PI values and a process similar to that used with the Boeing Bump correlation may be necessary to more closely estimate the PI.

COMPARISON TO SMOOTHNESS SPECIFICATIONS

Comparison of Simulation to FAA Regional Guidance for Smoothness

Several FAA regions have incorporated smoothness acceptance criteria into specifications for flexible pavements. There is an effort to incorporate the criteria into the FAA national specification. Table 4 shows the guidance for acceptance criteria using California style profilograph criteria placed in construction project specifications throughout several FAA Regions. The guidance has been in use for nearly 10 years. A pay adjustment schedule is associated with this guidance for most projects.

Table 4. Current FAA Smoothness Guidance (Hot Mix).

Over 30,000 lb	30,000 lb or less	Short Sections	Pay Factor
0.0–7.0	0.0–10.0	0.0-15.0	100%
7.1-9.0	10.1–11.0	15.1–16.0	98%
9.1-11.0	11.1–12.0	16.1–17.0	96%
11.1–13.0	12.1–13.0	17.1–18.0	94%
13.1–14.0	13.1–14.0	18.1–20.0	92%
14.1–15.0	14.1–15.0	20.1–22.0	90%
15.1& up	15.1& up	22.1& up	Corrective work req’d

The ranges in Table 4 were converted to estimated straightedge tolerance using the 85 PWL regression equation from Figure 4 at a 0.50-inch grade tolerance. The results are listed in Table 5. The data indicate that when 15% of the measurements are outside the estimated tolerance, all values are well below the 0.25-inch straightedge tolerance in the current specification.

Table 5. California PI as Straightedge Criteria (Hot Mix).

CA Profilograph			Pay Factor	85pwl Straightedge Tolerance		
>30k	**<30k**	**Short**		**>30k**	**<30k**	**Short**
7	10	15	100%	0.108	0.133	0.167
9	11	16	98%	0.125	0.140	0.173
11	12	17	96%	0.140	0.148	0.179
13	13	18	94%	0.154	0.154	0.184
14	14	20	92%	0.161	0.161	0.194
15	15	22	90%	0.167	0.167	0.203
15.1	15.1	22.1	Correct	0.168	0.168	0.203

Comparison of Simulation to Virginia Department of Transportation IRI Guidance for Smoothness

The Virginia DOT uses the IRI as acceptance criteria (11). Table 6 shows a comparison between information in report VDOT 99-R-19 Measuring, Achieving, and Promoting Smoothness of Virginia's Asphalt Overlays (by Kevin K. McGhee, P.E. Senior Research Scientist), and the estimated straight edge tolerance. The ranges in Table 6 were converted to an estimated straightedge tolerance using the 85 PWL regression equation found in Figure 3. The data indicate that when 15% of the measurements are outside the estimated tolerance, all values are well below the FAA 0.25-inch straightedge tolerance. The data also compare favorably with the over 30,000-pound aircraft column in the FAA California profilograph specification provided a 0.50-inch grade tolerance is used.

Table 6. Pay Adjustment Schedule for 1998 Virginia DOT Construction Season.

IRI at Completion (m/km)	Pay Factor	Straightedge 85pwl Tolerance
0.710	104	0.077
0.790	103	0.086
0.870	102	0.095
0.950	101	0.104
1.100	100	0.122
1.260	98	0.140
1.420	95	0.158
1.580	90	0.176
1.581	Correct	0.177

DISCUSSION OF RESULTS

This study shows that FAA grade and straightedge tolerances in construction specifications work in unison to provide pavements that are safe for aircraft operations when the tolerances are within the quality limits specified. A limited check of field-measured profiles indicates that the straightedge tolerance is routinely satisfied, but the grade tolerance may not reflect in-service pavement conditions. The study also indicates that FAA grade tolerance is critical for aircraft operations and the current restriction should not be relaxed for runway pavements.

The PROVIEW software may prove to be a valuable tool in developing alternate acceptance criteria for taxiway and apron pavements at smaller airports. Refinements to the software made by the researchers during the conduct of this study have enhanced its capabilities. The final product is expected in 2002.

ACKNOWLEDGEMENTS/DISCLAIMER

The software described in this paper was developed by the FAA Airport Technology Research and Development Branch, Dr. Satish K. Agrawal, Manager. The contents of the paper reflect the views of the author, who is responsible for the facts and accuracy of the data presented within. The contents do not necessarily reflect the official views and policies of the FAA. The paper does not constitute a standard, specification, or regulation.

REFERENCES

1. Advisory Circular 150/5370-10A Standards for Specifying Construction of Airports, Federal Aviation Administration, www.faa.gov/arp/150acs.htm
2. FAA Order 5300.1F Modification to Agency Standards, Federal Aviation Administration
3. Unpublished Report with Computer Software-- Pavement Profile Analytical Tool, Federal Aviation Administration, William J, Hughes Technical Center, Atlantic City, New Jersey
4. The IRI comes from the 1982 World Bank International Road Roughness Experiment in Brazil.
5. ASTM E 1170 Standard Practice for Simulating Vehicular Response to Longitudinal Profiles of Traveled Surfaces, ASTM Volume 04.03, 100 Barr Harbor Drive, West Conshohocken, PA
6. BeBord, K.J., Gervais, E.L., Runway Roughness Measurement, Quantification, and Application, the Boeing Method, Boeing Document D6-81746, November, 1995.
7. ASTM E 1274 Standard Test Method for Measuring Pavement Roughness Using a Profilograph, ASTM Volume 04.03, 100 Barr Harbor Drive, West Conshohocken, PA
8. Crystal Ball is a registered trademark of Decisioneering, Inc.
www.decisioneering.com
9. Excel is a registered trademark of Microsoft, Inc
10. Cubic Spline, and Curve Fit for MS Excel - XlXtrFun.xll
www.mathtools.net/Excel/Fitting_and_Interpolation/index.html
11. VDOT 99-R-19 Measuring, Achieving, and Promoting Smoothness of Virginia's Asphalt Overlays (by Kevin K. McGhee, P.E. Senior Research Scientist)
www.virginiadot.org/vtrc/main/online_reports/pdf/99-r19.pdf

APPENDIX

TABLE A1 PROVIEW OUTPUT--AVERAGES OVER SIMULATED 10,000-foot RUNWAY

Straightedge Length	Quality Level	Grade Tolerance (in.)	Straightedge Tolerance (in.)	Straightedge Index (in.)	Boeing Bump	IRI (m/km)	California Profilograph Index (in/mi)
12-foot	85 PWL	0.125	0.05	0.029	0.063	0.503	0.04
12-foot	85 PWL	0.125	0.10	0.059	0.086	1.009	2.58
12-foot	85 PWL	0.125	0.15	0.089	0.116	1.512	10.64
12-foot	85 PWL	0.125	0.20	0.118	0.152	2.009	22.49
12-foot	85 PWL	0.125	0.25	0.147	0.188	2.510	36.02
12-foot	85 PWL	0.125	0.35	0.206	0.260	3.509	63.12
12-foot	85 PWL	0.125	0.45	0.264	0.334	4.505	92.82
12-foot	85 PWL	0.125	0.55	0.322	0.407	5.501	122.62
12-foot	85 PWL	0.125	0.65	0.380	0.480	6.501	152.71
12-foot	85 PWL	0.125	0.75	0.438	0.554	7.501	182.36
12-foot	85 PWL	0.250	0.05	0.030	0.095	0.510	0.12
12-foot	85 PWL	0.250	0.10	0.059	0.114	1.006	3.56
12-foot	85 PWL	0.250	0.15	0.089	0.137	1.512	11.13
12-foot	85 PWL	0.250	0.20	0.119	0.164	2.018	22.00
12-foot	85 PWL	0.250	0.25	0.148	0.195	2.518	33.74
12-foot	85 PWL	0.250	0.35	0.207	0.264	3.525	59.47
12-foot	85 PWL	0.250	0.45	0.266	0.335	4.520	89.24
12-foot	85 PWL	0.250	0.55	0.323	0.409	5.515	120.42
12-foot	85 PWL	0.250	0.65	0.382	0.482	6.515	147.93
12-foot	85 PWL	0.250	0.75	0.441	0.555	7.513	177.76
12-foot	85 PWL	0.375	0.05	0.030	0.131	0.523	0.25
12-foot	85 PWL	0.375	0.10	0.059	0.146	1.012	4.12
12-foot	85 PWL	0.375	0.15	0.088	0.166	1.509	12.88
12-foot	85 PWL	0.375	0.20	0.118	0.190	2.011	23.69
12-foot	85 PWL	0.375	0.25	0.148	0.215	2.520	35.04
12-foot	85 PWL	0.375	0.35	0.207	0.273	3.526	59.98
12-foot	85 PWL	0.375	0.45	0.267	0.337	4.536	85.12
12-foot	85 PWL	0.375	0.55	0.326	0.411	5.537	114.06
12-foot	85 PWL	0.375	0.65	0.384	0.482	6.531	144.89
12-foot	85 PWL	0.375	0.75	0.442	0.556	7.531	175.91
12-foot	85 PWL	0.500	0.05	0.031	0.168	0.539	0.54
12-foot	85 PWL	0.500	0.10	0.059	0.180	1.021	4.52
12-foot	85 PWL	0.500	0.15	0.088	0.198	1.516	13.50
12-foot	85 PWL	0.500	0.20	0.118	0.219	2.012	25.03
12-foot	85 PWL	0.500	0.25	0.147	0.242	2.514	36.79
12-foot	85 PWL	0.500	0.35	0.207	0.295	3.526	61.44
12-foot	85 PWL	0.500	0.45	0.266	0.353	4.539	87.81
12-foot	85 PWL	0.500	0.55	0.326	0.417	5.541	113.67
12-foot	85 PWL	0.500	0.65	0.386	0.486	6.550	140.01
12-foot	85 PWL	0.500	0.75	0.444	0.559	7.550	170.98

TABLE A1 PROVIEW OUTPUT--AVERAGES OVER SIMULATED 10,000-foot RUNWAY

Straightedge Length	Quality Level	Grade Tolerance (in.)	Straightedge Tolerance (in.)	Straightedge Index (in.)	Boeing Bump	IRI (m/km)	California Profilograph Index (in/mi)
12-foot	85 PWL	0.625	0.05	0.031	0.206	0.559	0.97
12-foot	85 PWL	0.625	0.10	0.060	0.217	1.033	5.40
12-foot	85 PWL	0.625	0.15	0.089	0.232	1.522	14.38
12-foot	85 PWL	0.625	0.20	0.118	0.251	2.019	25.91
12-foot	85 PWL	0.625	0.25	0.147	0.273	2.515	38.25
12-foot	85 PWL	0.625	0.35	0.207	0.320	3.525	62.55
12-foot	85 PWL	0.625	0.45	0.266	0.375	4.536	89.15
12-foot	85 PWL	0.625	0.55	0.326	0.433	5.546	115.85
12-foot	85 PWL	0.625	0.65	0.385	0.497	6.550	142.54
12-foot	85 PWL	0.625	0.75	0.445	0.560	7.560	167.37
12-foot	85 PWL	0.750	0.05	0.032	0.245	0.583	1.75
12-foot	85 PWL	0.750	0.10	0.060	0.254	1.047	6.43
12-foot	85 PWL	0.750	0.15	0.089	0.267	1.531	15.38
12-foot	85 PWL	0.750	0.20	0.118	0.284	2.024	26.81
12-foot	85 PWL	0.750	0.25	0.147	0.304	2.522	39.13
12-foot	85 PWL	0.750	0.35	0.206	0.349	3.520	65.38
12-foot	85 PWL	0.750	0.45	0.266	0.398	4.535	89.69
12-foot	85 PWL	0.750	0.55	0.325	0.455	5.542	117.79
12-foot	85 PWL	0.750	0.65	0.385	0.513	6.554	143.75
12-foot	85 PWL	0.750	0.75	0.444	0.576	7.555	169.41
12-foot	85 PWL	0.875	0.05	0.033	0.284	0.609	2.61
12-foot	85 PWL	0.875	0.10	0.060	0.292	1.061	7.67
12-foot	85 PWL	0.875	0.15	0.089	0.304	1.544	16.59
12-foot	85 PWL	0.875	0.20	0.118	0.318	2.032	27.79
12-foot	85 PWL	0.875	0.25	0.147	0.337	2.529	40.06
12-foot	85 PWL	0.875	0.35	0.206	0.380	3.520	66.13
12-foot	85 PWL	0.875	0.45	0.265	0.427	4.524	92.55
12-foot	85 PWL	0.875	0.55	0.326	0.477	5.546	115.65
12-foot	85 PWL	0.875	0.65	0.384	0.535	6.549	145.35
12-foot	85 PWL	0.875	0.75	0.444	0.593	7.564	171.37
12-foot	85 PWL	1.000	0.05	0.034	0.323	0.638	3.51
12-foot	85 PWL	1.000	0.10	0.061	0.330	1.079	8.80
12-foot	85 PWL	1.000	0.15	0.090	0.341	1.556	17.60
12-foot	85 PWL	1.000	0.20	0.119	0.354	2.042	28.72
12-foot	85 PWL	1.000	0.25	0.148	0.371	2.534	40.76
12-foot	85 PWL	1.000	0.35	0.206	0.411	3.526	67.38
12-foot	85 PWL	1.000	0.45	0.264	0.457	4.527	94.07
12-foot	85 PWL	1.000	0.55	0.324	0.507	5.529	120.11
12-foot	85 PWL	1.000	0.65	0.386	0.557	6.553	142.64
12-foot	85 PWL	1.000	0.75	0.443	0.615	7.556	172.96

TABLE A1 PROVIEW OUTPUT--AVERAGES OVER SIMULATED 10,000-foot RUNWAY

Straightedge Length	Quality Level	Grade Tolerance (in.)	Straightedge Tolerance (in.)	Straightedge Index (in.)	Boeing Bump	IRI (m/km)	California Profilograph Index (in/mi)
12-foot	85 PWL	1.125	0.05	0.035	0.362	0.669	4.37
12-foot	85 PWL	1.125	0.10	0.062	0.369	1.098	10.05
12-foot	85 PWL	1.125	0.15	0.090	0.379	1.570	18.89
12-foot	85 PWL	1.125	0.20	0.119	0.390	2.052	29.56
12-foot	85 PWL	1.125	0.25	0.148	0.406	2.542	41.76
12-foot	85 PWL	1.125	0.35	0.206	0.442	3.535	67.29
12-foot	85 PWL	1.125	0.45	0.265	0.487	4.526	94.29
12-foot	85 PWL	1.125	0.55	0.324	0.534	5.532	121.15
12-foot	85 PWL	1.125	0.65	0.384	0.583	6.546	146.11
12-foot	85 PWL	1.125	0.75	0.444	0.638	7.559	173.21
12-foot	85 PWL	1.250	0.05	0.036	0.401	0.702	5.42
12-foot	85 PWL	1.250	0.10	0.062	0.408	1.119	11.01
12-foot	85 PWL	1.250	0.15	0.090	0.417	1.584	19.94
12-foot	85 PWL	1.250	0.20	0.119	0.428	2.066	30.54
12-foot	85 PWL	1.250	0.25	0.148	0.441	2.552	42.47
12-foot	85 PWL	1.250	0.35	0.206	0.476	3.541	67.99
12-foot	85 PWL	1.250	0.45	0.265	0.518	4.533	94.59
12-foot	85 PWL	1.250	0.55	0.323	0.563	5.534	122.31
12-foot	85 PWL	1.250	0.65	0.382	0.613	6.534	149.20
12-foot	85 PWL	1.250	0.75	0.444	0.661	7.559	173.26